QUANTUM-INSPIRED VEDIC SOCIETY ALGORITHMS

A

Synopsis

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1. Introduction

Most real-world optimization problems are very difficult to solve. They typically fall under the category of NP-hard problems which means that those problems are at least as difficult as the most difficult problems in NP (Non-deterministic Polynomial). Decision Problems in NP are those which cannot be solved in polynomial time but, if an Oracle provides a solution then the solution can be verified in polynomial time.

Different optimization techniques have been developed to solve these problems. These can be classified into two broad classes — exact and stochastic. Exact techniques are highly-effective for small-sized problems. However, as the size of the problems gets larger, they become too complex for exact techniques in terms of the increased computation time necessary to be expended. In such cases stochastic techniques are utilized [1]. These techniques do not guarantee to find the global optimal solution. They only provide a satisficing solution or a "near-optimal" solution within "reasonable" computation time. Several stochastic optimization algorithms have been proposed with varying degree of success when applied on wide variety of optimization problems. Some of the prominent ones among these are as follows [2].

(i) Random Search

(ii) Heuristics

(iii) Hill Climbing

(iv) Simulated Annealing

(v) Tabu Search

(vi) Neural Networks

(vii) Particle Swarm Optimization

(viii) Ant Colony optimization

(ix) Evolutionary Algorithms

1.1. Evolutionary Algorithms

Meta-heuristics [3] are stochastic techniques widely studied and applied to solve NP-hard problems. Evolutionary algorithms (EAs), the leading meta-heuristics, are nature-inspired algorithms,

which simulate the natural biological evolution of species to solve various optimization problems. EAs have been successfully applied on a wide range of problems of planning, design, simulation, identification, control and classification [4]. The success of EAs on various optimization and search problems have made them very popular. Almost all the big companies have some reported applications of Evolutionary Algorithms viz., NASA, Lockheed Martin, Glaxo Smith Kline, LBS Capital Management, Texas Instruments, John Deere & Co., Volvo, British Petroleum etc.

In 1859, Charles Darwin [5] came up with an explanation for the relationship of the living beings with the environment and called it natural selection. According to this theory, the individuals that are well adapted to the environment live longer and have higher chances of reproduction than the others less adapted to the environment. Better traits of these fitter individuals are passed on to the next generation. Thus, each succeeding generation has individuals that are even better adapted to the environment and have higher chances of survival and reproduction. The same idea of evolution or natural selection is simulated in EAs.

EAs operate on a population of candidate solutions and iteratively evolve the population to find the optimal solution for the given problem. Just as in case of natural evolution of the species, reproduction, mutation, recombination, and selection operators are used to evolve the population. The pseudo-code of a prototypical EA is as follows.

General pseudo-code of Evolutionary Algorithms
1. Define optimization parameters
2. Generate the initial population of individuals randomly
3. Evaluate the fitness of each individual
4. Repeat following steps
4.1. Generate new individuals using selection, crossover and mutation operators
4.2. Evaluate the fitness of new individuals
4.3. Select a new population of individuals by replacing the least-fit individuals with new better individuals in the previous population

In EAs, exploration and exploitation are the fundamental operations performed to search for the optimum solution in the solution space. A proper balance in the computational effort devoted to these two operations is critical to the success of any EA. Exploration is used to explore the whole feasible solution space to find better solutions. Exploitation is used to explore the solution space around the solution in hand, to get more promising solutions nearby. These exploration and exploitation activities

in evolutionary algorithms are typically done by crossover and mutation operators, respectively; whose frequency of application can be varied in a specific implementation. They can also be chosen according to the landscape of solution space in a given problem and the data / size of the problem on which the algorithm is going to be applied.

The problems with EAs are that they might show premature convergence, slow convergence or sensitivity to the choice of parameters. This makes the design of a successful EA more an art than a science. Several thumb rules are available for getting better designs but they are more in the form of heuristics rather than in the form of exact recipes. Further, there is a "No Free Lunch" theorem [6] that essentially states that the performance of an EA is no better than random search when averaged over all possible problems. However, this only means that a specific EA including some understanding of the domain function which is to be optimized has to be designed for a given optimization problem rather than expecting a single EA implementation to work for all kinds of problems.

A wide range of EAs have been proposed in last few decades. Genetic Algorithms (GAs) [7], Evolution Strategy (ES) [8][9], Evolutionary Programming (EP) [10], Genetic Programming (GP) [11] and Differential Evolution (DE) [12] are some well-known EAs, all simulating natural evolution with some variations or additions.

Several other enhancements in EAs have been proposed over time. Parallel and Distributed EAs [13], Hybrid EAs [14], Quantum inspired EAs [15][16] are some of the improved and advanced EAs. More recently the inspiration paradigm of EAs has begun including social interaction and human behaviour exchange collectively called social evolution of individuals. Thus, ideas from societal, cultural and civilizational evolution have also been incorporated in EAs.

1.2. Quantum Inspired Evolutionary Algorithms

Quantum Inspired Evolutionary Algorithms (QIEAs) were first introduced by Narayanan *et al.* [17] in 1995 to solve the traveling salesman problem, in which the crossover operation was performed based on the concept of interference. This initial endeavour motivated others to introduce quantum mechanism in wider extent while designing EAs. Han and Kim [18] proposed a more practical QIEA that uses Q-bit representation and Q-gate as a variation operator. Zhang [15] and Manju *et al.* [16] have studied various QIEAs and their applications on optimization problems.

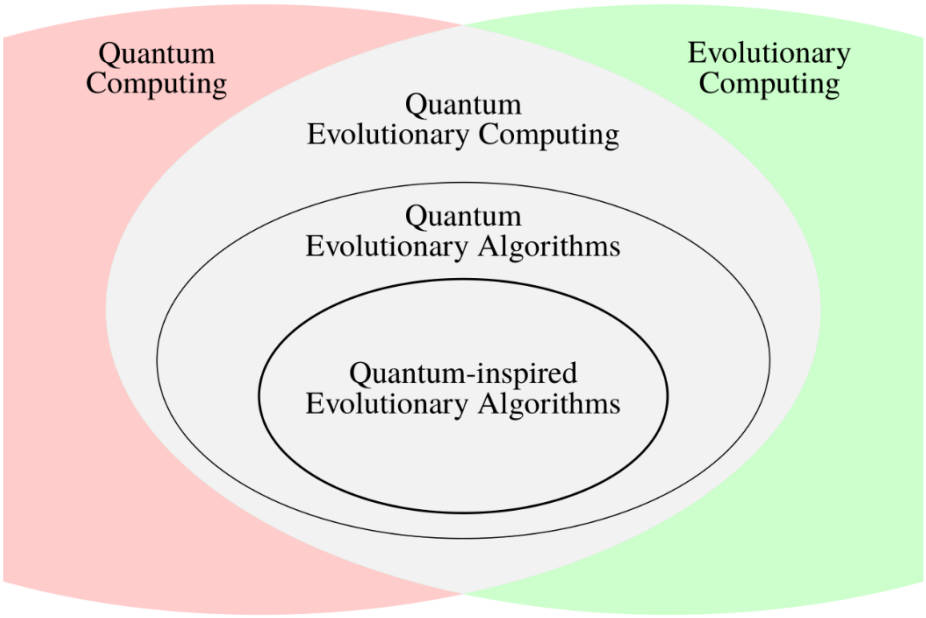

Figure 1: Quantum and Evolutionary Computing Subfields [19]

QIEAs integrate basic concepts and principles from Quantum Mechanics like Q-bit representation, superposition, Q-gate and entanglement etc. These were incorporated in EAs to make them more powerful. Population individuals in QIEAs are represented in a Q-bit representation, so that only one individual is enough to represent the whole search space in case where the solution strings are binary strings. Q-gates are used as evolutionary operators to enhance the solution individuals. Following are three main characteristics of a QIEA.

— It adopts a new representation called Q-bit representation, to describe population individuals.

— It uses a new operator called Q-gate to find or generate new individuals.

— It can exploit the whole search space with a few individuals, even with a single individual.

QIEAs can be considered as a kind of Estimation of Distribution Algorithms (EDAs). But the advantage of QIEAs over EDAs is that the QIEAs require no auxiliary selection methods and replacement strategies. Various variants of QIEAs have been proposed. They can be categorized into three types – binary observation QIEA (bQIEA), real observation QIEA (rQIEA) and QIEA-like algorithms (iQIEA) [15].

QIEAs have been successfully utilized for the solution of both combinatorial optimization problems as well as real parameter function optimization problems [20].

2. Socio-inspired Evolutionary Algorithms

Swarm-based algorithms use the social behaviour of insects, birds and animals. Particle swarm optimization [21], Ant colony optimization [22], Artificial bee colony [23] are some notable swarm-based algorithms. Social phenomena of humans have inspired another set of algorithms collectively called Social Algorithms [24].

2.1. Social Algorithms

Human beings optimize everything in their daily routine. Whatever humans do they try to do it in an optimized way (according to them). The social interaction between humans makes them evolve and solve their problems. The actual real-life evolution of individuals is not biological only, it has social evolution, in more extent. Biological evolution of individuals happens one time only when they are generated, but the social evolution might happen whenever an individual interacts with someone having one or more better characteristics. Hence, the influence of the better individuals lets others evolve by interacting with them and simulating them. Recently social behaviour of human beings is also incorporated to provide better algorithms as humans are considered as the most intelligence species on Earth [25]. These new algorithms simulate the social/cultural interaction and behaviour exchange seen in humans [24]. Social evolution is much faster than the biological evolution [26] and, therefore, Social Algorithms are expected to perform better than algorithms inspired by biological evolution. This motivated different researchers to develop algorithms inspired by the social interaction. Problems in data analyzing, modelling [27], cognitive sciences [28] etc. have been solved using these social algorithms. Some recent socially inspired algorithms are as follows.

1. Bonyadi *et al.* [29] proposed an algorithm to solve traveling thief problem by simulating the multi-component real-world problems' solving behaviour of experts. The traveling thief problem is solved by decomposing the problem into knapsack problem and traveling salesman problem and then solving each separately with some communication links between the both.

2. V. Taratukhin and Y. Yadgarova [30] incorporated socio-inspiration on different types of designing and manufacturing agents to create an integrated multi-layer product life cycle environment

to solve the problem of future product life cycle systems. The agents in this multi-layer environment can communicate with one-another and are capable of self-adaption.

3. S. M. Kala *et al.* [31] were inspired by the sociological idea of "sui genetis social reality" given by Durkheim [32]. They proposed an interference estimation and channel allocation performance prediction algorithm called CALM (Channel Assignment Link-weight Metric) to estimate and mitigate the inferences in Wireless Mesh Networks (WMNs).

2.2. Socio-inspired Evolutionary Algorithms

The ideas of social interaction, behaviour exchange and human learning mechanisms motivated some researchers to propose EAs which are inspired by one or more of these social processes. These new EAs inspired by the social processes are Socio-inspired EAs (SIEAs). The basic Social Algorithms mentioned above use social inspiration to solve some specific problems in the literature. SIEAs can be applied to solve many search and optimization problems because EAs have general applicability over a wide variety of problems. The only requirement to apply an EA is an appropriate formulation of the fitness function of the problem.

The basic idea of SIEAs is contained in the Vedic text as follows.

सहनाववतु सहनौ भुनक्तु सहवीर्यं करवावहै। तेजस्विनावधीतमस्तु मा विद्विषावहै।।

–May it (the Brahma) protect us both (teacher and pupil)! May it enjoy us both! May we acquire strength together! May our knowledge become bright! May we never quarrel! [33].

In SIEAs, evolution happens at two levels of interaction – at individual level and at group level. Individuals in SIEAs form some groups on the basis of societal grouping like families, villages, colonies, states, etc. as seen in the real world, each trying to be the best. The basic idea of these algorithms is as follows. An individual improves by interacting and simulating better characteristics of others. Specifically, an individual is influenced by his / her parents, siblings, neighbours (in the same group and / or from the another group), other group members, group leader (a member having best fitness in the group), global leader (a member having best fitness in the whole solution space i.e., in all groups) etc. The best group among all these groups has the best individuals and hence the global optimal solution.

Pseudo-code of SIEAs
1. Define optimization parameters
2. Generate the initial population of individuals randomly
3. Create clusters of individuals based on some social grouping
4. Evaluate the fitness of each individual
4. **Repeat** following steps
5.1. Select the best-fit individuals
5.2. Improve individuals' fitness through interaction with the best-fit neighbour in their own group or in outer group
5.3. Evaluate the new fitness of individuals
5.4. Select new population by replacing the least-fit individuals with new better individuals in the previous population

SIEAs being EAs inherit all the advantages of EAs. Additionally, they have their own advantageous features of self-organization as being inspired by the self-organizing phenomena. The notion of SIEAs started with the Cultural Algorithms, introduced by Reynolds in 1994 [26]. This idea motivated some recent SIEAs like Society and Civilization Optimization algorithm (SCO) [34], Imperialist Competitive algorithm (ICA) [35], Social Emotional Optimization algorithm (SEOA) [36], Anarchic Society Optimization algorithm (ASO) [37], Teaching–learning-based optimization (TLBO) [38], Cultural Evolution algorithm (CEA) [39], Cohort Intelligence (CI) [40], Social learning optimization (SLO) [41], and Social Group Optimization (SGO) [42] etc.

SCO is inspired from the social behaviour of humans seen among society individuals. The ICA simulates the socio-political behaviours seen across imperialist nations which compete to take possession of weaker colonies or empires. SEOA simulates the decision-making capabilities of individuals guided by their emotions. ASO simulates the greedy and chaotic human behaviour they use to achieve their goals. TLBO simulates the influence of teachers on the learning process of students. CEA is based on Steward's theory of socio-cultural interaction. CI is based on the cooperative and competitive behaviour of individuals and their self-learning behaviour while achieving some individual goal. SLO mimics the evolution of individuals at different levels – genetic and cultural evolution. Another innovative algorithm Social Group Optimization mimics the human behaviour of solving a complex problem collectively. These and other socio-inspired algorithms are succinctly summarized in following Table 1.

Table 1: A brief review of SIEAs

S. No.	Name of Algorithm (Authors)	Basic Idea	Applications	References
1.	Cultural Algorithm (Robert G. Reynolds)	Two-fold cultural interaction seen between consequent cultures	Transient Optimization of Natural Gas Networks, Sea-surface weak target detection, etc.	[26, 43, 44, 45]
2.	Social Cognitive Optimization (Xie *et al.*)	Albert Bandura's Social Cognitive Theory (SCT), which argues that the human learning is done by observing the behaviour of others	Combined heat and power economic dispatch, Constrained nonlinear programming, etc.	[46, 47, 48, 49, 50]
3.	Society and Civilization Algorithm (T. Ray and K. Liew)	Social behaviour of human and insect societies to improve themselves	Welded Beam Design, Spring Design, Speed Reducer Design, Three-Bar Truss Design	[34]
4.	Imperialist Competitive Algorithm (E. Atashpaz-Gargari and C. Lucas)	Imperialistic competition that happens among countries to improve themselves	Structural damage detection, Performance prediction of circular saw machine, etc.	[35, 51, 52]
5.	Parliamentary Optimization (A. Borji)	Behaviour of political parties seen in a parliament head election process	Web pages classification, Personalized learning paths building, etc.	[53, 54, 55, 56]
6.	Human-inspired Algorithm (Zhang *et al.*)	Enhanced version of Bee Algorithm (BA) based on humans rather than bees	Continuous function optimization with and without constraints	[57, 58, 59]
7.	Social Emotional Optimization Algorithm (Y. Xu *et al.*)	Human behaviour of decision making guided by their emotions	Machine training and parameter settings for support vector machine, Beamforming of linear antenna arrays, etc.	[36, 60, 61]
8.	Election Campaign Optimization (Wenge Lv *et al.*)	Influence of candidates on voters in election campaign	Public Transport Scheme Optimization, Video Tracking, etc.	[62, 63, 64]
9.	Anarchic Society Optimization (Amir Ahmadi-Javid)	Human behaviour of searching the best suitable place to live upon	Water distribution networks, single and continuous multi-reservoir systems, etc.	[37, 65, 66]

10.	Teaching Learning Based Optimization (R. Rao *et al.*)	Influence of the teachers on the students	Frequency Regulation in Two Area Thermal-Solar Hybrid Power System, Resource-Constrained Project Scheduling Problem, etc.	[67, 68, 69]
11.	Group Leaders Optimization (A. Daskin and S. Kais)	Influence of the leaders in social groups	Disruption management in Cloud manufacturing, Integrated process planning and scheduling, etc.	[70, 71, 72]
12.	Cohort Intelligence (Anand J. Kulkarni)	Self-supervised learning behaviour of a human to achieve a goal	Constrained Engineering Design, Finite Element Mesh Smoothing, etc.	[40, 73, 74]
13.	Cultural Evolution Algorithm (H. Kuo and C. Lin)	Steward's socio-cultural interaction theory	Serial-parallel system design and Bridge system design, etc.	[39, 75]
14.	Social-based Algorithm (F. Ramezani and S. Lofti)	Implementation of ICA on two different levels	Flood-routing Modeling, Artificial Neural Network weights optimization, etc.	[76, 77, 78]
15.	Election Algorithm (H. Emami and F. Derakhshan)	Presidential election used to elect a president in a country	Rastrigin, Griewank, Rosenbrock and Ackley benchmark functions.	[79]
16.	Social Learning Optimization (Z.-Z. Liu)	Process of human intelligence evolution and Bandura's social learning theory	QoS-aware cloud service composition, Effective task scheduling in Cloud Computing.	[41, 80]
17.	EVolutive Election Based Optimization (M. Pourghanbar *et al.*)	General electoral system	Ackley and Shubert Benchmark functions, Traveling salesman problem, BTS localization problem, etc.	[81, 82]
18.	Ideology Algorithm (T. Ting Huan *et al.*)	Competitive behaviour of party members trying to improve their ranking in the party	a set of 50 widely used benchmark functions and 25 benchmark functions from CEC2005	[83, 84]
19.	Social Group Optimization (S. Satapathy and A. Naik)	Human skill of using the social behavioural traits to solve a complex problem	RGB Image Multi-level Thresholding, Distortion of Data Sets to Shield the Sensitive Patterns in Trading Alliances, etc.	[42, 85, 86]
20.	Duelist Algorithm	Human learning mechanism in duels	PID controller tuning, Mud Injection Pressure in Oil Drilling, etc.	[87, 88, 89]
21.	Socio Evolution & Learning Optimization (M. Kumar *et al.*)	Social learning behaviour of family individuals from other families and family members	a set of 50 benchmark functions	[24]

3. Vedic Society

The Vedic Society was very different from the present society. The societal system of that time was perfectly organized for the well-being and all-around development of the society along with the peace and happiness of the human beings. The roles of humans were so cleverly defined and organized that the inter-dependency of the population individuals became tightly coupled and required a proper social interaction path to achieve some task. While every individual was playing his/her role faithfully, the social development of the humans and the society was at apex. Roles and duties of humans are described in Vedas and other ancient scriptures.

The primary teachings from Vedas recommended that every individual should get taught, select a profession for himself depending on his nature, thoughts, actions, and culture, take a promise to pursue that profession, and ought to pursue that profession. Three predominant professions as per Vedas are — professions based on Knowledge, based on Justice / state Administration and based on finance / economics. The followers of these three classes of professions were called “Brāhmaṇa”, “Kṣatriya”, and “Vaiśya”, respectively, whereas followers of other than these professions were called “Śūdra”. Hence the society was a mixture of four types of persons categorized according to their profession.

Tasks of these classes were defined as.

(i) Brāhmaṇa — praying, teaching, protecting sacred learning through generations, etc.

(ii) Kṣatriya — management, security and protection of society, fighting in wartime etc.

(iii) Vaiśya — farming, business, merchandising etc.

(iv) Śūdra — laboring and servicing to others, building architectures etc.

This classification of humans according to their nature was termed in Sanskrit as “Varṇa-catuṣya, Varṇa-catuṣṭaya, or Cāturvarṇya” system. The word *Varṇa-catuṣya*, is a composite Sanskrit word, made of two words – “Varṇa” which means *type, order, class* or *color* and “catuṣya” which means *four*, in number. Hence, Varṇa-catuṣya means *four types, four orders, four classes* or *four colors*, namely – Brāhmaṇa, Kṣatriya, Vaiśyaand Śūdra, as stated in mainly considered texts of Indian Sanskrit literature [90, 91, 92, 93].

ब्राह्मणोऽस्य मुखमासीद्बाहू राजन्यः कृतः। ऊरू तदस्य यद्वैश्यः पदभ्यां शूद्रो अजायत।।

— the Brāhmaṇa was produced from his mouth, Rājanya (Kṣatriya) from his both arms. Vaiśya from his thighs, and Śūdra from his feet [90, 91, 92].

चातुर्वर्ण्यं मया सृष्टं गुणकर्मविभागशः।…

— I have created the four classes (Varṇa)–Brāhmaṇa, Kṣatriya, Vaiśya and Śūdra – according to innate properties and actions … [93].

This categorization is based on the karma (actions) of people.

ब्राह्मणक्षत्रियविशां शूद्राणां च परन्तप। कर्माणि प्रविभक्तानि स्वभावप्रभवैर्गुणैः।।

— the duties of Brāhmaṇa, Kṣatriya, Vaiśya, as also of Śūdra are determined by properties that are born out of their nature [93].

The caste system of the present societal system is a distorted form of the varṇa system in which the social groupings are done on the basis of the birth rather than the nature of the individual. The Vedic social grouping was not hereditary. In Ṛgveda, there are references that people of different varṇa can live in one house, which is against the present societal system.

कारूरहं ततो भिषगुपलप्रक्षिणी ननना। नानाधियोवसूयवोऽनु गा इव तस्थिम…

— a bard / artisan am I, my son or dad is a leech, my daughter or mother is a wheat-grinder. Striving for wealth, with varied plans, we follow our desires like kine … [90].

According to Manusmṛti, everyone was considered as Śūdra at his / her birth and then their actions / habits define in which group they were going to be.

जन्मना जायते शूद्रः संस्काराद्भवेत् द्विजः।…

— a man is no better than a Śūdra at his birth. He is called Dvija because of consecration [94].

The social interaction of Vedic period was very complex. Whenever any new work had to started by the Kṣatriyas, or Vaiśyas they interacted with the Brāhmaṇas and Śūdras, to do prayer (Yajña) on the land prepared and cleaned by the Śūdras. There were specialists in each class from whom interested individuals learnt how to do a particular task. Joint families were transferring their cultural and societal knowledge to the next generation. Marriage was the only compulsory rite for all classes. It was not viewed as a secular contract but it was a religious ritual. Eight types of marriage were present at that time [94]. The marriage was a binding force through the lifetime. Divorce was not present, but

there are evidences of levitating and marrying widows. The leaders in each class were elected by the members of that class [92].

Education system of Vedic period was based on the Gurukul system, where every student was treated as its own child by the teachers, and the education was in the form of real-life actions and applications. Teachers in Gurukul system were the most significant influencing entity. Actual furnishing of individuals happened in Gurukulas.

Being based upon the interest and working or usability of a member this classification of individuals into classes was a very good framework to optimize the resources of the society and to make it more robust and well-organized. Individuals with the same area of interest belong to one of the four predefined classes, where each of the class optimizes their objectives on their own level.

4. Motivation

The literature survey presented in the above sections clearly brings out the tremendous potential of the social algorithms and QIEAs, as evidenced by their utilization on a wide variety of optimization problems. The social algorithms presented in the literature have been inspired from the various aspects of human endeavours including cultural and social interaction, imperialistic tendencies etc.

All these ideas have primarily been motivated from Western Social structures. The Vedic Society System of India in the early days was a cradle of civilization for the whole world as it was one of the most advanced societies of its time. It was very good in both terms of economic prosperity and the development of a well-thought-out social structure such that everybody had a role to play in the society with associated financial security.

However, the literature survey clearly indicates that absolutely no work has been done on designing Evolutionary Algorithms, SIEAs and QSIEAs based on the societal structure of the Vedic Society. The excellence of the Vedic Social Structure and the paucity of any work whatsoever of social algorithms based on the Vedic society provides the motivation for the work proposed in this thesis.

5. Proposed Work

Social inspiration in Evolutionary algorithms as shown in above literature review have been incorporated and used for solving various optimization problems that showed better results than other

EAs. Again, Vedic Society is known to have better optimization characteristics, hence provides a good framework to propose a new socio-inspired EA. The primary objective of this work is to propose a new EA simulating the Vedic Society System as an inspirational idea. Below works are going to be accomplished along-with.

(i) A deeper analysis of the Vedic society and its strengths in social structure would be made. The primary aim of this study would be to understand the societal elements that propelled the Vedic society to be one of the best civilizations of its time.

(ii) The elements of the Vedic society would be integrated to develop a Socio-inspired Evolutionary Algorithm based on Vedic Society framework – VSA i.e., *Vedic Society Algorithm* for search and optimization.

(iii) Elements from QIEAs would be integrated to develop QVSA i.e., a *Quantum-inspired Vedic Society Algorithm* which would attempt to bring together in good measure, the strengths of both the QIEAs and the VSA for the solution of more difficult optimization algorithms.

(iv) Performance of the VSA and QVSA would be analysed on a wide variety of benchmark functions. These could be both for combinatorial optimization problems and, more specifically, the Subset Selection Problems and, also, real parameter function optimization.

(v) The above endeavours would be utilized to produce a user-friendly QVSA toolbox that can be used with benefit for the solution of wide variety of optimization problems. The toolbox would provide the user / programmer facility to easily include or exclude a particular feature to promote under search or increase rated of convergence.

(vi) Parallelization of the proposed QVSA would also be attempted to enable faster solution of hitherto un-attempted problems and large instance sizes of even those problems which have been solved earlier.

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